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MAGNETIC ENRICHMENT OF QUARTZ SANDS. ANALYSIS OF SEPARATOR OPERATION

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A comparative analysis is made of magnetic separators used to decrease and stabilize the iron content in quartz sand. It is shown that obsolete electromagnetic roll and rotor separators are cumbersome, unreliable, and expensive to operate. The construction of belt roll separators using permanent magnets has a number of irremovable defects that impede the use of such separators in domestic enterprises. Thus the most acceptable separators for magnetic enrichment of quartz sand at domestic enterprises are magnetic drum separators with an LSO series high-intensity magnetic system.

Key words: magnetic separator, quartz sand, magnetic enrichment, glassmaking.

It is well known that iron present in the mix materials is one of the harmful substances that lower the light transmission of glass. The iron content in the mix used in domestic glassmaking works is lowered and stabilized by equipping the mix-making process cells with magnetic separators which perform the magnetic enrichment of the mix materials [1]. Ordinarily, magnetic enrichment of quartz sand, which is the main component of the glass mix, is sufficient to improve the quality of glass and stabilize the glassmaking process. Since a substantial part of the iron-containing impurities present in quartz sand are finely dispersed and weakly magnetic, special magnetic separators, characterized by high magnetic induction (> 0.6 T), are used to remove these impurities effectively.

To separate materials by the magnetic separation method the magnetic system of the separator must produce a nonuniform magnetic field, and the magnitude of the magnetic field and gradient of the intensity of the magnetic field intensity are the most important characteristics of the separation, which directly affects the results of the enrichment [2]. Currently, the magnetic induction and magnetic induction gradient values are used to characterize magnetic separators, which is convenient but not entirely correct [3]. The structural particulars and method of regulation of a separator, the method of dispensing material, the efficiency of the separator (thickness of the layer of enriched materials) also influence the magnetic enrichment process. The magnetic enrichment method can be used to eliminate completely strongly and weakly magnetic iron-containing impurities which are not bound with the sand mechanically.

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Over the past 20 years fundamental changes have taken place in the construction of magnetic separators in the developed countries, intended for magnetic enrichment of quartz sand. Obsolete electromagnetic separators have been replaced with separators whose magnetic systems are based on iron-neodymium-boron permanent magnets. Such magnets have made it possible to obtain enrichment results which are no worse and at substantially lower cost.

Today there are four type of magnetic separators used for dry magnetic enrichment of quartz sands. We shall analyze the advantages and disadvantages of these separators. To make economic assessments of the yearly costs enrichment sections with the same productivity were equipped with each type of separator. The calculations were performed using as the productivity of sections 10 tons/h, cost of 1 kW of electricity 2.5 rubles, and loading of sections 20 h/day for 300 days/yr. The cost of 1 m^2 of Kevlar belt was taken to be US $100. The computational details are omitted.

Electromagnetic Roll Separators

Description and principle of operation. Series ÉVS electromagnetic roll separators have been manufactured in Russia since the 1960s. In separators of this type the magnetic field in the gap between the stationary magnetic circuit and the roll rotating in the horizontal plane is created by means of an electromagnetic coil. A diagram of the magnetic enrichment scheme is shown in Fig. 1. The rotating steel roll has special protrusions on which a nonuniform magnetic field needed for separation is created. The material to be enriched flows into the gap between the stationary magnetic circuit and the rotation roll. The magnetic impurities are attracted to

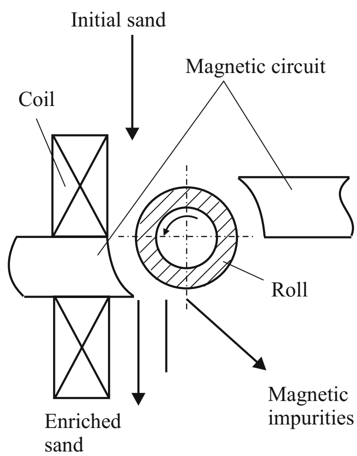

Fig. 1. Electromagnetic roll separator.

the protrusions of the rotating roll and, continuing to roll together with it, acquire kinetic energy. Leaving the gap together with the roll the magnetic impurities no longer feel the magnetic force attracting them to the protrusions on the roll (the magnetic field outside the gap is weak) and, continuing their inertial motion due to the acquire kinetic energy they are unloaded. Nonmagnetic quartz sand moves downward unperturbed under gravity along the surface of the stationary magnetic circuit and is unloaded at an earlier time.

Technical characteristics of magnetic systems. The magnetic induction in the working zone is greater than 1.2 T and the approximate induction gradient in the working zone is 0.07 T/mm.

Quality of the enrichment of quartz sand. For nominal productivity and single-stage enrichment in electromagnetic roll separators, complete separation of the iron-containing impurities which are not bound mechanically with the sand grains does not occur. Evidence of this is the fact that the iron content in the quartz sand continues to decrease with repeated enrichment. Electromagnetic roll separators do a poor job of removing steel debris particles. Some of the steel debris which is present in the quartz sand being enriched and sticks to the roller is not unloaded, rotating together with it and changing the geometry of the magnetic field in the working gap. This degrades magnetic enrichment. To remove the steel debris particles the rollers must be cleaned with the magnetic field switched off. Other steel debris particles are not extracted by the roller and accumulate on the stationary magnetic circuit in the form of a “beard” at the location where the enriched quartz sand converges. A part of the “beard” falls off periodically and gets into the enriched sand. When the magnetic field of the separator is switched off, the entire “beard” consisting of the steel debris particles gets into the enriched sand, forming in it a nonuniformity of iron content.

Advantages of separators. Essentially, this is the scheme implemented in metal for extracting weakly magnetic minerals and magnetic enrichment of quartz sand. Electromagnetic roll separators are water-cooled and can be used for magnetic enrichment of hot quartz sand.

Disadvantages of Separators. The disadvantages of electromagnetic roll separators are typical for obsolete equipment – high consumption of electricity and large mass. For example, the 2ÉVS-36/100 separator with capacity 5 – 6 tons/h with respect to quartz sand consumes 30 kW · h of electricity. The mass of this separator is 8 tons. The unreliability of the construction of the electromagnetic rollers of separators is due to the fact that as the rollers rotate in a magnetic field eddy currents which destroy the plummer bearings arise. Replacing these bearings requires a great deal of work and partial disassembly of the separator with removal of the rollers. The mass of each of two rollers in the 2ÉVS-36/100 separator is 800 kg. With the separator operating continually the time between repairs can be only 2 – 3 months.

Yearly costs with productivity 10 tons/h. The approximate cost of repairs is 6000 US$/yr. The consumable materials are the bearings. The cost of electricity is 30,000 US$/yr. The total yearly costs without the consumable materials for content of the enriched section with productivity 10 tons of quartz sand per hour will be 36,000 US$/yr (1,080,000 rubles).

Conclusions. Electromagnetic roll separators possess a number of structural disadvantages, have high costs per content, and do not give consistently high quality of magnetic enrichment. There is no advantage to buying new electromagnetic roll separators to enrich quartz sand. Since the cost per content is high, it is cost-effective to replace existing electromagnetic roll separators with modern separators with magnetic systems based on permanent magnets.

Electromagnetic Rotor Separators

Description and principle of operation. Even though there is a world trend to replace electromagnetic separators with magnetic systems based on permanent magnets, a new type of electromagnetic separator appeared on the market relatively recently – rotor series ÉRS. The magnetic enrichment scheme is presented in Fig. 2. In electromagnetic rotor separators the magnetic field in the gap between the stationary magnetic circuit and the rotor rotating in a vertical plane is created by means electromagnetic coils. A rotor possesses special “checkered plates” (the developers’ terminology), on which the nonuniform magnetic field required for separation is created. The magnetic impurities are attracted to the checkered plates of the rotating rotor and, continuing to rotate with it, are carried into the zone where the magnetic fraction is unloaded, which is also the zone where the stationary magnetic circuit terminates. On exiting, together with the rotor, the gap the magnetic impurities are no longer subjected to the magnetic force attracting them to the checkered plates of the rotor (the magnetic field outside the gas is weak) and are unloaded by gravity. The nonmagnetic quartz sand moves under gravity vertically downwards along the surface of the stationary magnetic circuit. The manufacturer proposes that separators with two rotors set on the same axis, i.e., separa-

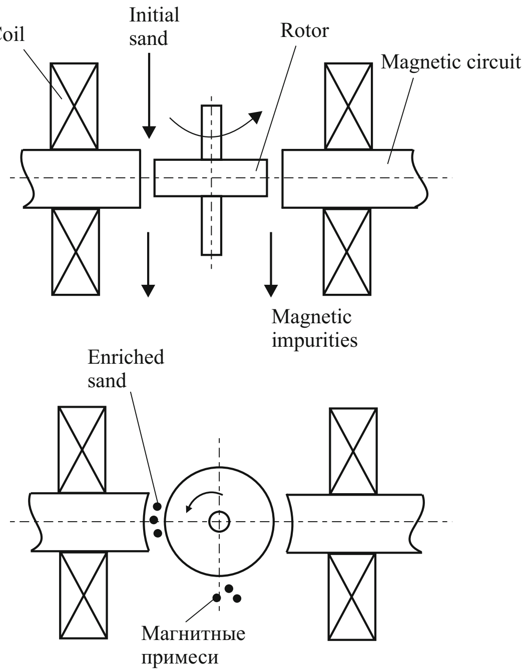

Fig. 2. Electromagnetic rotor separator.

tors with two enrichment stages, be used. Strongly magnetic impurities (for example, steel debris particles) should be removed at the first stage in a magnetic field 0.4 T, and weakly magnetic minerals should be removed at the second stage in a magnetic field with high induction.

Technical characteristics of magnetic systems. The magnetic induction in the working zone is > 0.4 T in the first stage of enrichment and > 1.2 T in the second stage. The approximate induction gradient in the working zone is 0.07 T/mm.

Quality of the enrichment of quartz sand. The magnetic characteristics of electromagnetic rotor separators are close to those of electromagnetic roll separators and the enrichment quality is apparently differs very little. Probably, the presence of the first enrichment stage makes it possible to remove the strongly magnetic impurities (steel debris particle) more completely. Since separators of this type are not widely used, it is difficult to report anything else about them.

Advantages of the separators. Electromagnetic rotor separators are distinguished by lower energy consumption than electromagnetic roll separators, are water-cooled, and can be used for magnetic enrichment of hot quartz sand.

Disadvantages of the separators. Even though they appeared on the market relatively recently, electromagnetic rotor separators are already obsolete. Their main disadvantages are high electric power consumption and very large mass. For quartz sand productivity 8 tons/h the electricity consumption is 33 kW (1,2ÉRS-2 separator). The mass of the 1,2ÉRS-2 separator is 24 tons. The mass of electromagnetic rotor separators is several-fold larger than that of the electromagnetic roll separators examined above. The unreliability of the construction of electromagnetic rotor separators is due to the fact that the emf arising with the rotor rotating in a magnetic field generates currents that flow through the plummer bearings and destroy them. The manufacturer asserts that these currents have been eliminated, which is presented a substantial advantage over electromagnetic roll separators. This assertion is doubtful and can only be checked in practice. A fundamental difference between the two types of electromagnetic separators lies only in the rotation axis, which is horizontal for roll separators and vertical for rotor separators. In both cases a conducting body (roller or rotor) rotates in a magnetic field, which results in the appearance of emf and, in consequence, currents that destroy the plummer bearings [3]. It is possible that the time between repairs for electromagnetic rotor separators is longer than for electromagnetic roll separators because of the large size of the bearings. The price for a long period between repairs will be more complicated repairs because of the large mass of the of the electromagnetic rotor separators and of the rotors themselves.

Yearly cost with productivity 10 tons/h. The approximate cost of repairs is 6000 US$ per year. The consumable materials are the bearings. The cost of electricity is 20,625 US$. Neglecting the cost of the consumable materials the yearly cost of the content of the enrichment section with productivity 10 tons of quartz sand per hour will be 26,625 US$ per year (799,000 rubles).

Conclusion. Considering the disadvantages indicated above and the high cost of content, the purchase of electromagnetic rotor separators for enriching quartz sand is not cost-effective.

Belt Roller Separators with Permanent Magnets

Description and principles of operation. In the developed countries belt roller separators with permanent magnets have replaced electromagnetic separators and are manufactured by a large number of firms. The construction of foreign belt roller separators with permanent magnets has served as a foundation for copying by manufacturers in the Commonwealth of Independent States and Russia, which also now manufacture separators of this type. Even though they have many drawbacks, these separators are actively sold on the Russian market. The enrichment scheme is shown in Fig. 3. A belt roller separator with permanent magnets is a conveyor whose drive roll is a magnetic roller. The magnetic system of the roller consists of iron-neodymium-boron permanent magnets, which gives high magnetic characteristics of the separator. The quartz sand to be enriched is fed onto a thin Kevlar conveyer belt and, moving with the belt, reaches the magnetic roller. The magnetic fraction is attracted to the conveyer belt of the magnetic system of the roller. With further motion the conveyer belt with the magnetic fraction leaves the surface of the roller, the magnetic system of the roller no longer acts, and unloading occurs under gravity. Not undergoing attraction the enriched quartz sand descends ear-

lier along a different trajectory under the centrifugal force and gravity.

Technical characteristics of the magnetic systems. The magnetic induction in the working zone > 1.2 T and the approximate induction gradient in the working zone is 0.3 T/mm.

Quality of the enrichment of quartz sand. For nominal loads the results of the enrichment of quartz sand on belt roll separators and electromagnetic roll separators is essentially the same. Complete removal of iron-bearing impurities which are not mechanically bound with the sand grains does not occur in the enrichment of quartz sand on belt roller separators. The iron content in the quartz sand decreases with repeated enrichments. For this reason belt roller separators ordinarily have two or three enrichment stages, since the required result is not obtainable with a single stage. As a rule, the magnetic systems of the rollers in different stages have different magnetic characteristics. The magnetic fraction present as dust in the air settles on the surface of a roller, forming a “coat.” When the thickness of the coat exceeds 0.5 mm the quality of the separation is degraded. The enrichment quality is very sensitive to the condition of the Kevlar belt. Timely replacement of the belt is important. Patches are sometimes used as a savings; this degrades the quality of the separation.

The scheme used for magnetic enrichment of quartz sand at domestic enterprises includes magnetic separation immediately after drying, and cases where the sand temperature is much higher than 100°C are not infrequent. Because of the absence of cooling by water the permanent magnets in the magnetic systems of the rollers undergo demagnetization, i.e., the separator becomes unusable. This is manifested as an increase of the iron content in the enriched quartz sand. Apparently, such demagnetization and the subsequent increase of the iron content in the enriched quartz sand occur at all enterprises using belt roll separators for enrichment of hot quartz sand.

Example. In 2007, at the request of the technical services of the glass works “Krasnoe Ékho” JSC (Vladimir Oblast’, Russia, the reason for the increase of the iron content in quartz sand enriched with a SMRS-12/120-AR two-stage belt roll separator manufactured by the Scientific and Industrial Firm “Prodékologiya” and acquired by the firm was studied. It was found that the characteristics of the magnetic rollers were degraded. For example, the magnetic induction on the surface of the top roller (first enrichment stage) was 0.63 T instead of the nominal 0.7 T; the value for the bottom roller (2nd stage of enrichment) was 0.28 T instead of the nominal 1.2 T. The degradation of the magnetic enrichment was due to the temperature demagnetization of the permanent magnets of the rollers by the hot quartz sand.

Advantages of the separators. In accordance with the current trends, permanent magnets are used in the magnetic systems of belt roll separators. This gives acceptable quality of enrichment of cold quartz sand.

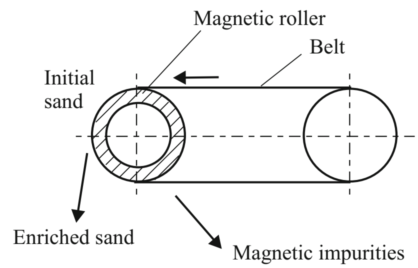

Fig. 3. Belt roller separators with permanent magnets.

Disadvantages of the separators. Belt roll separators are a relatively successful piece of laboratory equipment not intended to be used under the conditions of domestic enterprises. For example, they contain a short-life, expensive Kevlar conveyor belt. The standard replacement time of the belt is once per month. The magnetic fraction present in the form of dust in the air settles on the surface of the magnetic roller, which accelerates the wear of the belt. The state of the surface of the magnetic roller must be checked periodically, which ordinarily is not done. To remove the “coat” or replace the belt, the separator must be partially disassembled, the belt must be removed, and the surface of the roller carefully cleaned. Belt replacement or cleaning the roller is a laborious operation and must be done by specially trained highly qualified workers. The lack of cooling by water makes it impermissible to use belt roller separators for magnetic enrichment of quartz sand.

Yearly expenditures. The approximate cost of the repairs is 3000 US$ per year. The consumable material is the Kevlar which costs 7200 US$. The cost of electricity is 2000 US$. The total yearly expenditures on the content of the enrichment section with productivity 10 tons of quartz sand per hour are 12,200 US$ (366,000 rubles).

Conclusion. Belt roll separators have irremovable structural drawbacks that impede their use in domestic enterprises. Replacement of the separators will lower the production costs and increase the quality of the enriched quartz sand.

Magnetic Drum Separators with a High-Intensity Magnetic System with LMO Series Permanent Magnets

Description and principle of operation. Analysis of the drawbacks of the magnetic separators presented above shows that there is a need for an up to date, reliable, inexpensive, water-cooled, small-size magnetic separator, which does not require constant observation, for magnetic enrichment of quartz sand. Such separators (series LMO separators) have been built in the form of a magnetic drum separator equipped with a high-intensity magnetic system with iron-neodymium-boron magnets. It is precisely the high-intensity magnetic system whose characteristics are close to those of the magnetic systems of belt roll separators that distinguished series LMP separators from the ordinary drum separators with conventional magnetic systems [6, 7] and made it possi-

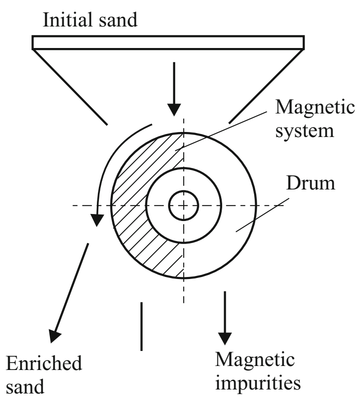

Fig. 4. Series LMO magnetic drum separators.

ble to use the new separators for high-quality enrichment of quartz sand.

The scheme of a series LMO separator is displayed in Fig. 4. Enrichment occurs when quartz sand is fed onto a drum rotating around a stationary high-intensity magnetic system. The drum is made of nonmagnetic, corrosion-resistant steel. The stationary magnetic system place inside the drum extends from 120 to 180° of circle. In the separation zone the magnetic system attracts magnetic impurities to the surface of the rotating drum. Continuing to rotate together with the drum the magnetic impurities are removed from the zone of action of the magnetic forces of the stationary magnetic system into the unloading zone. Since magnetic attraction forces do not act on the enriched quartz sand it descends from the drum earlier under the action of centrifugal force and gravity.

The first modification of LMO (magnetic enrichment line) series drum separators with a high-intensity magnetic system, designed to obtain enriched quartz sand of grades OVC-030 and OVS-025 from sands with initial iron oxide content of 0.030 – 0.040%, was fabricated in 1999 at the request of "Ramenskii GOK" JSC. The two LMO-5000-1 magnetic separators accepted for operation, each with productivity 5 tons/h, gave a total productivity of 10 tons/h [4].

Three modifications of LMO series separators have now been developed. The magnetic induction is > 0.6 T in the working zone for the first modification, > 0.7 T for the second modification, and > 0.95 T for the third modification. The approximate induction gradient in the working zone for LMO separators is 0.15 – 0.2 T/mm. The second (LMO-5000-2, 2003) and third (LMO-5000-3, 2007) modifications have better magnetic characteristics than the first modification. Practice has shown that the magnetic characteristic of the second modification are entirely sufficient for practically complete removal of iron-containing impurities present in quartz sand with single-stage enrichment. Such separators have been delivered to and are operating successfully at "Smerdomskii steklozavod" JSC, "BM-Astrakhan'-steklo" JSC (Astrakhan', Russia), and other locations.

After the appearance of the second and third modifications of the LMO separators the first modification was classified as an iron separator. The recommended application of this modification is high-productivity removal of impurities which in the course of shipment have entered quartz sand which was previously enriched or does not need enrichment. In this regime the small modules LMO-5000, 1999 (nominal productivity of a module in the enrichment regime is 5 tons/h) have been operated at the "Konsyumers-SkloZarya" JSC (Rovno Oblast', Ukraine) with each module having a productivity of 10 tons/h. The impurities removed are iron debris particles and iron oxides which entered the sand during shipment [5].

Quality of the enrichment of quartz sand. LMO series separators are worse than electromagnetic and belt roll separators with respect to the magnetic characteristics but not with respect to magnetic enrichment. It must be clearly stated that because of the multifactor nature of the magnetic enrichment process there is no direct relation between the magnetic properties of the separators and the results of enrichment. The effectiveness of any particular separator must be judged only with respect to one criterion – the results of magnetic enrichment with nominal productivity. So, the experience gained in commercial operation of the first modification of LMO series separators at the "Ramenskoe GOK" JSC showed that with respect to the quality of enrichment of quartz sand these separators were no worse than electromagnetic roll separators [4].

Many experiments on different types of quartz sand show that the second and third modifications of LMO series separators currently recommended for operation possess, on account of know-how, the capability of performing high-quality enrichment of quartz sand in one stage, i.e., repeated enrichment of quartz sand does not decrease the iron content. The results of experiments on magnetic enrichment of quartz sands from different deposits show that when operating at nominal productivities LMO separators of the second and third modifications currently are better than electromagnetic separators and two or three stage belt roll separators with permanent magnets.

Advantages of separators. The construction of LMO series magnetic drum separators with a high-intensity magnetic system is compact, simple, and reliable. Practice has shown that the total time of continuous operation of LMO series separators in a regular regime and without technical servicing is years. The service life of the shells of the drums is at least five years. The magnetic systems of LMO series drum separators are water-cooled; these separators are designed for magnetic enrichment of hot quartz sand. The operation of the separators does not require observing the work. The LMO series separators do not have all the drawbacks of electromagnetic and belt roll separators.

The advantages of LMO series drum separators with a high-intensity magnetic system over electromagnetic separators are the higher quality of the enrichment with much

smaller mass and low electricity consumption and no laborious repairs. For example, the mass of the LMO-5000-2, 2003 separator with productivity 5 tons/h is 700 kg, the power consumption is 2.2 kW, and the dimensions are 1700 × 890 × 740 mm. The advantages of LMO series drum separators with a high-intensity magnetic system over belt rotor separators with permanent magnets are better quality of enrichment, possibility of magnetic enrichment of hot quartz sand, no need for observing the operation of separators, possibility of operating the separators in dusty enclosures, and no consumable materials. The LMO series separators are an innovative development with no foreign or domestic analogues.

Disadvantages of separators. They have been eliminated by perfecting the design.

Yearly expenditures. The cost of electricity is 2200 US$. There are no consumable materials. The total yearly expenditures on the content of the enrichment section with productivity 10 tons of quartz sand per hour are 2200 US$ (66,000 rubles).

Conclusions. LMO series magnetic drum separators with high-intensity magnetic system can used for magnetic enrichment of quartz sand under the conditions of domestic enterprises.

CONCLUSIONS

A comparative analysis of magnetic separators used to decrease and stabilize the content of iron in quartz sand showed that obsolete electromagnetic roll and rotor separators are cumbersome, unreliable, and expensive to operate. The replacement of such separators by modern separators with magnetic systems with permanent magnets is cost-effective.

Belt roll separators with permanent magnets have a number of irremovable structural defects that impede their use for enriching quartz sand under the conditions of domestic enterprises. If glass works are serious about the quality of their products and lowering production costs, previously purchased belt roll separators should be replaced.

Meanwhile, LMO series magnetic drum separators with a high-intensity magnetic system which have no analogs abroad or domestically have been manufactured in Russia in the last ten years. Separators of this type are completely serviceable and are better than electromagnetic roll separators and belt roll separators with respect to the quality of the enrichment of quartz sand. The construction of LMO series separators has been checked over time and is compact, simple, and reliable. The water cooling of the magnetic systems of the separators makes is possible to use them freely to enrich hot quartz sand. These separators have minimum yearly expenditures on content. LMO series separators do not require consumable materials and do not need regular maintenance or servicing; in addition, practice shows that they stabilize and decrease to very low levels the iron content in the main component of a mix — the quartz sand. This is an efficient and cost-effective replacement for all other types of magnetic separators intended for enriching quartz sand. LMO series separators could make it possible to lower the costs of the glassmaking process by using sands from local deposits.

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